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Title: E1039/SpinQuest Polarized Drell-Yan Experiment at Fermilab

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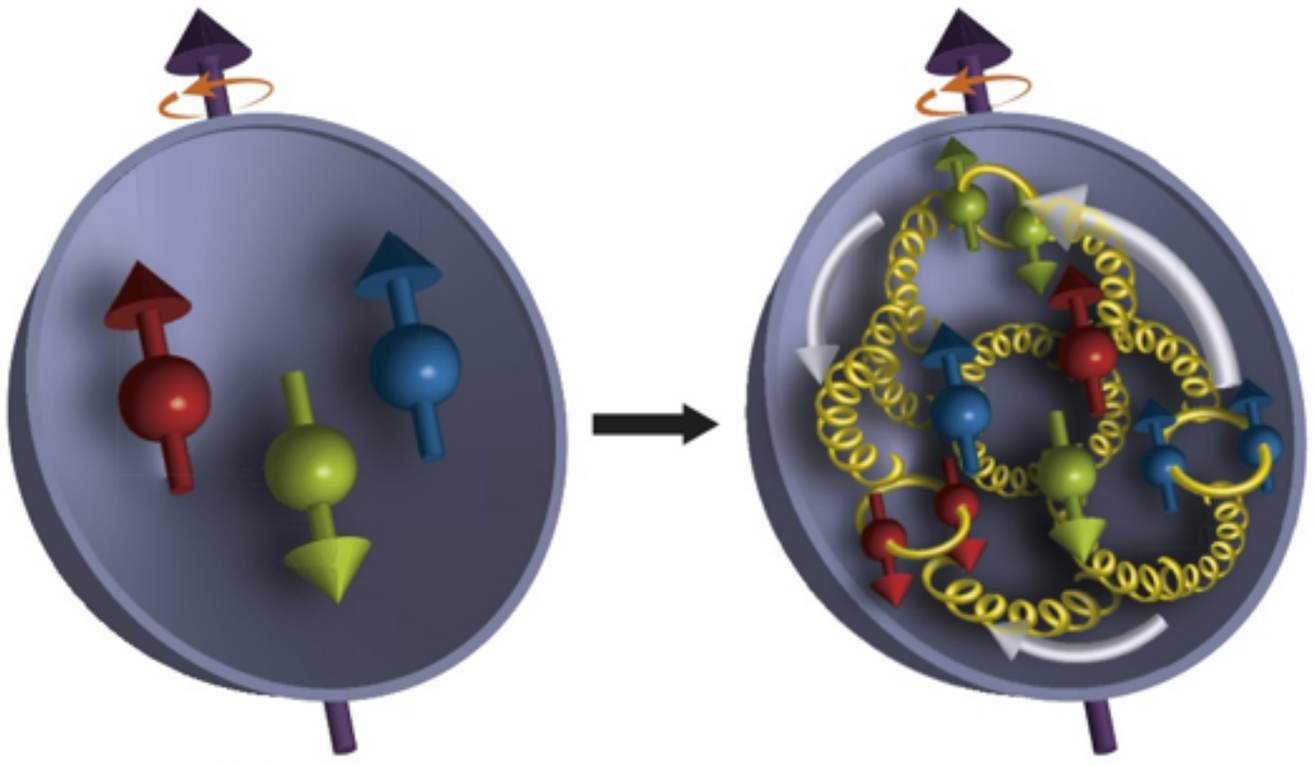
- **SpinQuest** Target : Arthur's talk
- **SeaQuest** Spectrometer : Me

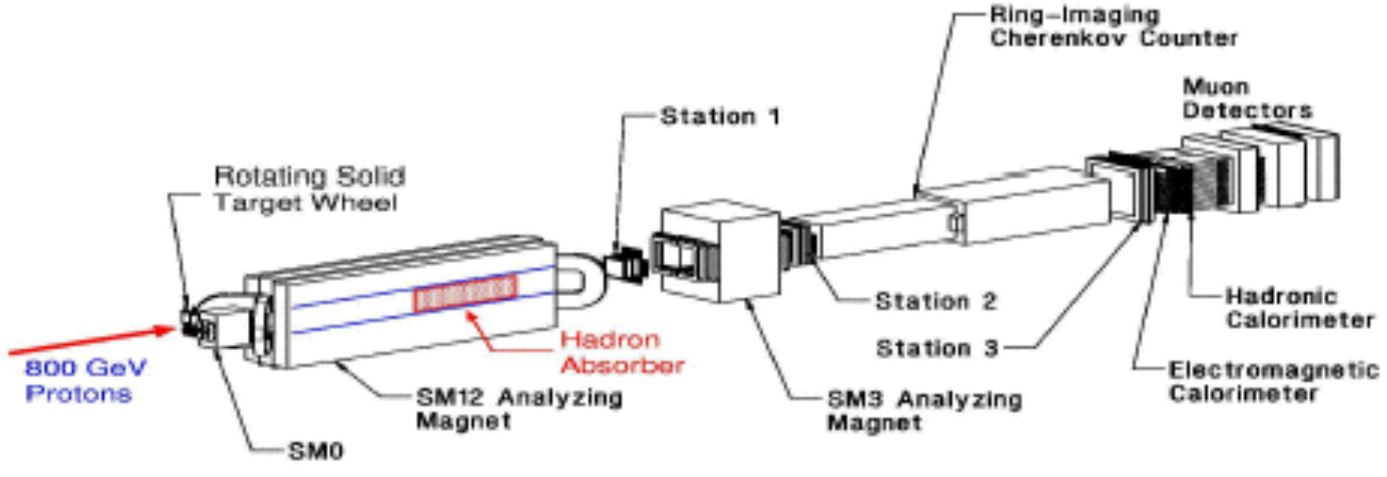
E1039/SpinQuest Polarized Drell-Yan Experiment at Fermilab

Chun-Min Jen
on behalf of the SpinQuest (E1039) Collaboration



Fermilab Dimuon Spectrometer: Fixed Target Drell-Yan

(E605 / 772 / 789 / 866 / 906)



1) Fermilab E772 (proposed in 1986 and completed in 1988)
"Nuclear Dependence of Drell-Yan and Quarkonium Production"

2) Fermilab E789 (proposed in 1989 and completed in 1991)
"Search for Two-Body Decays of Heavy Quark Mesons"

3) Fermilab E866 (proposed in 1993 and completed in 1996)
"Determination of $\bar{d}/\bar{u}$ Ratio of the Proton via Drell-Yan"

4) Fermilab E906 (proposed in 1999, ~~will run in 2010-2013~~)
"Drell-Yan with the FNAL Main Injector" decommission in spring 2018

Fermilab E1039 (proposed in 2013, will run in 2019-2021)
Now, it's commissioning (fall 2018…)

E1039 Collaboration

Rich Physics Extracted from First Polarized Drell-Yan at FNAL

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$

- SpinQuest opportunities:

★ Sea Quark Sivers (low-X, < 0.5)

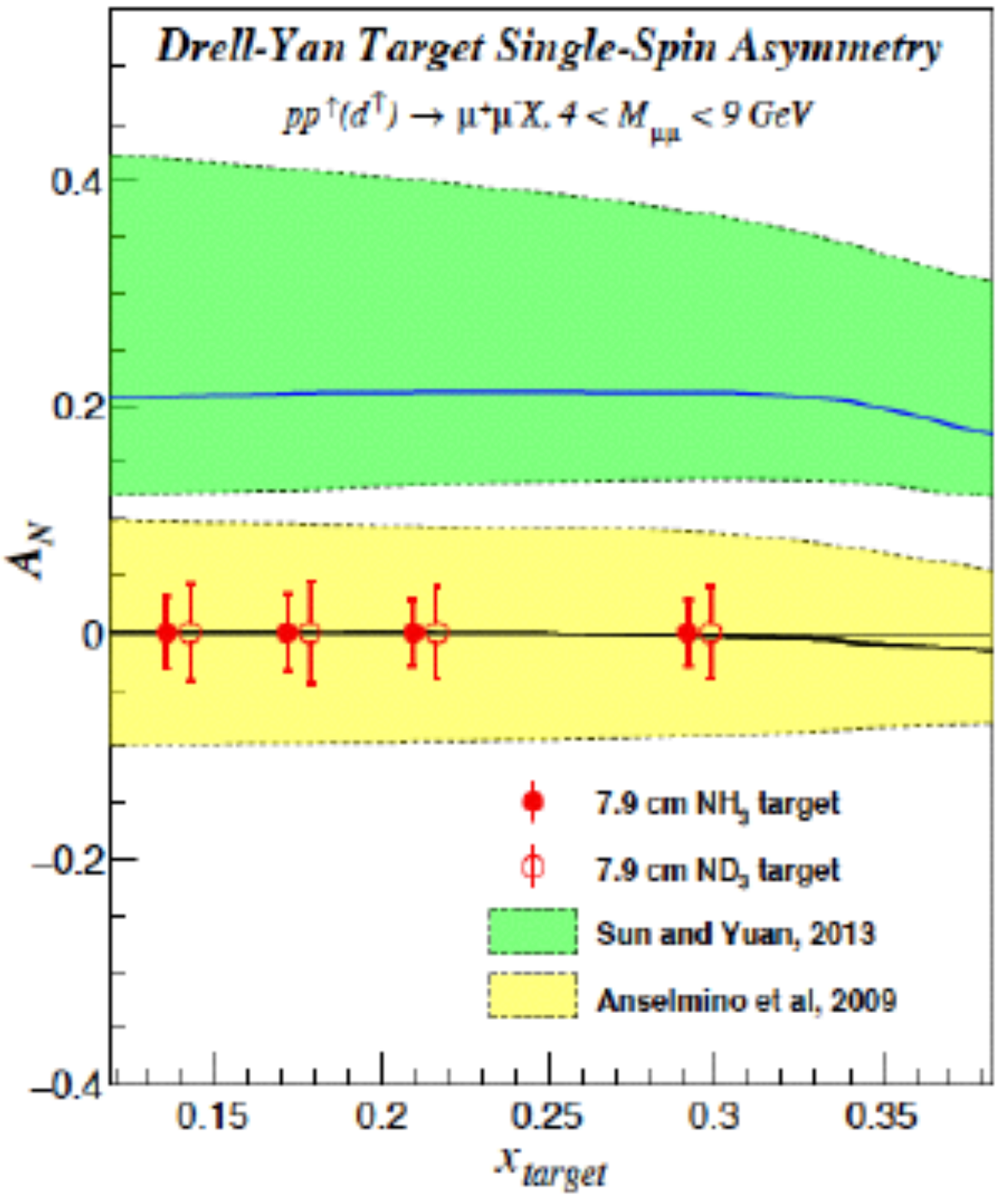
★ Gluon Sivers (high-X, > 0.5)

★ Transversity

★ open charm TSSA:

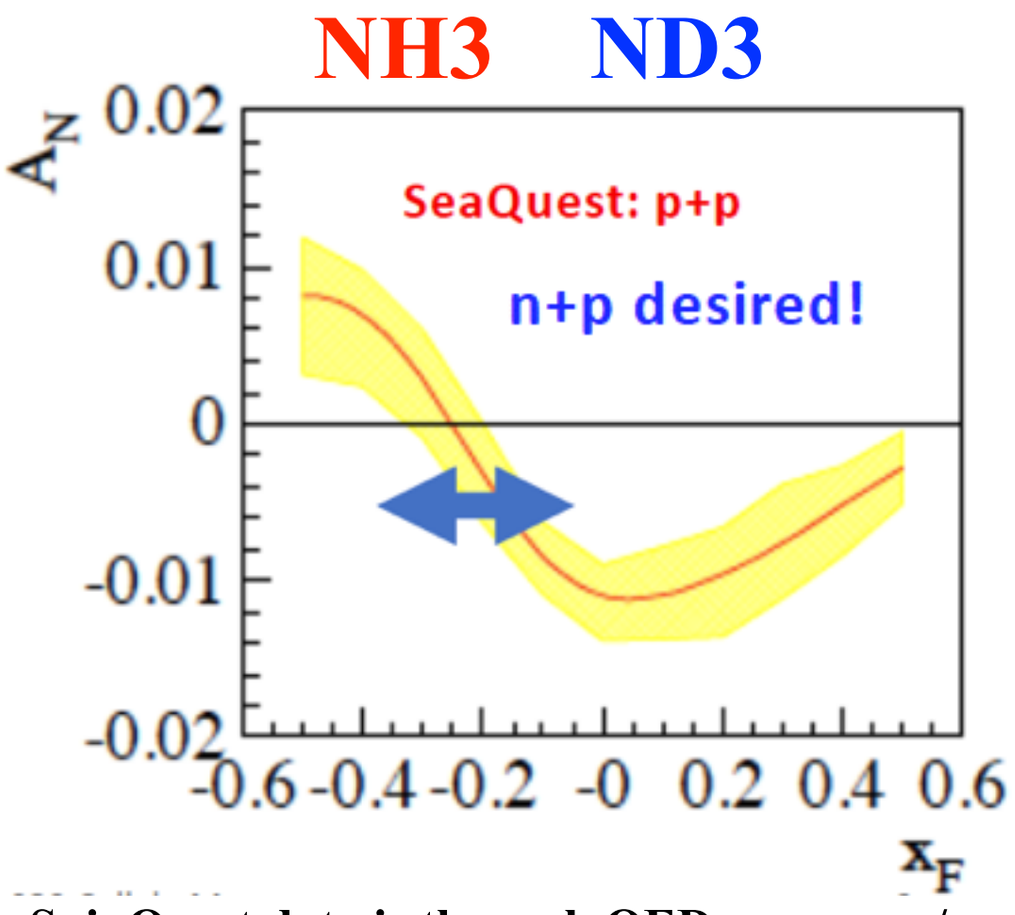
charm vs. anti-charm

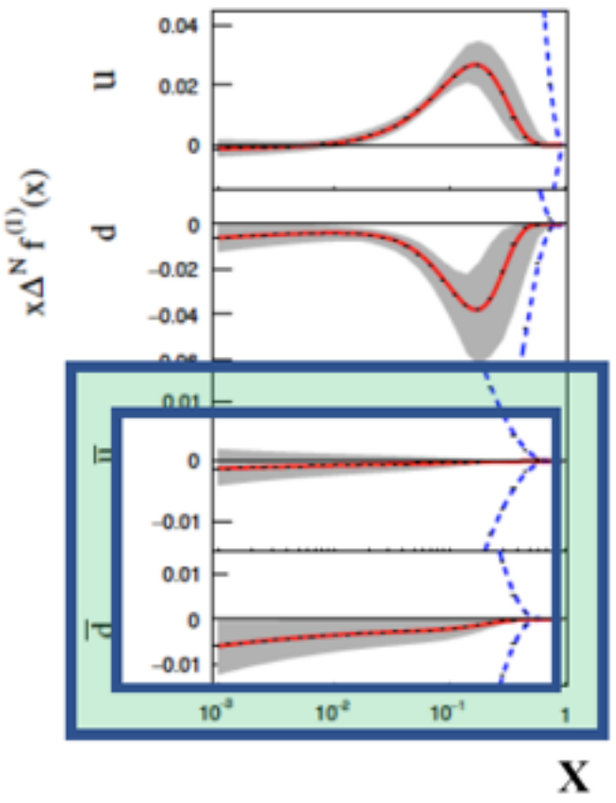
★ Dark photon and heavy photon

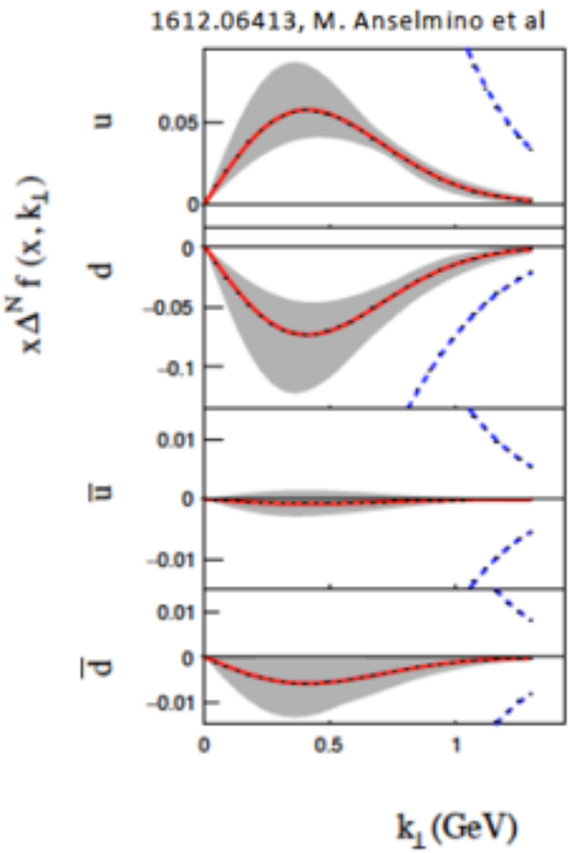


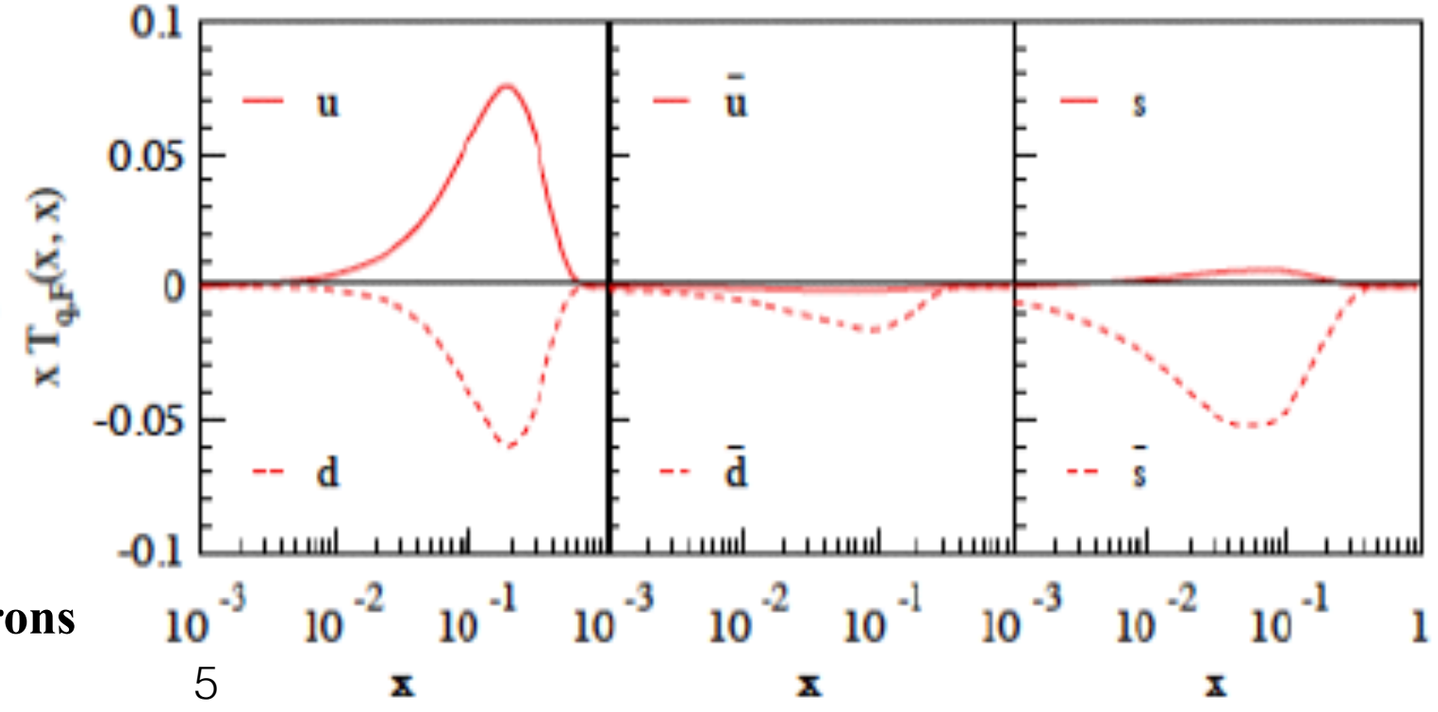
Sea Quark Sivers from global fits

Precise SpinQuest data helps further constrain sea quark Sivers!
Systematics uncertainties are critical in high-precision measurements!
(See Arthur's talk)









- **SpinQuest data is through QED process w/o:**
  1. **QCD final-state effect**
  2. **fragmentation function of final-state hadrons**

three PDFs used to describe K^{q}_{T} and/or $S^{n/q}_{T}$

three transversal quantities are

(1) nucleon's transversal spin (S^{n}_{T});

(2) quark's transversal spin (S^{q}_{T});

(3) quark's transversal momentum (K^{q}_{T})

three PDFs are

- (1) + (2) : Transversity
- (1) + (3) : Sivers function
- (2) + (3) : Boer-Mulders function

four types of Drell-Yen experiments at FNAL are as follows:

- polarized-beam & polarized-target Drell-Yan : Transversity (E10xx)
- **polarized-target & unpolarized-beam Drell-Yan : Sivers function (E1039)**
- polarized-beam & unpolarized-target Drell-Yan: Sivers function (E1027)
- unpolarized Drell-Yan : Boer-Mulders function (E605, E772, E789, E866, E906)

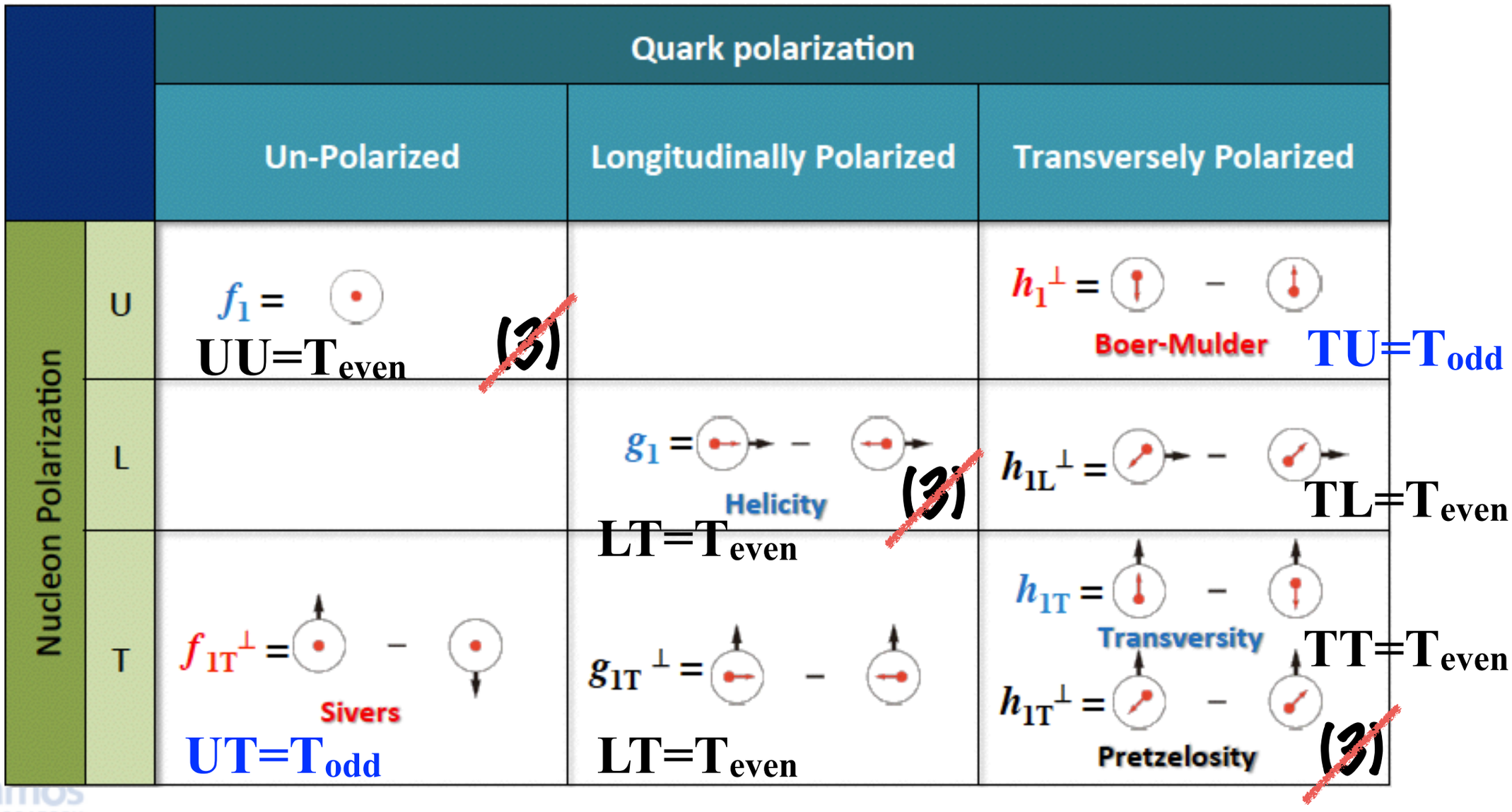
three transversal quantities are

(1) nucleon's transversal spin (S^n_T);

(2) quark's transversal spin (S^q_T);

(3) quark's transversal momentum (K^q_T) - "off-diagonal" terms

→ Nucleon Spin
→ Quark Spin

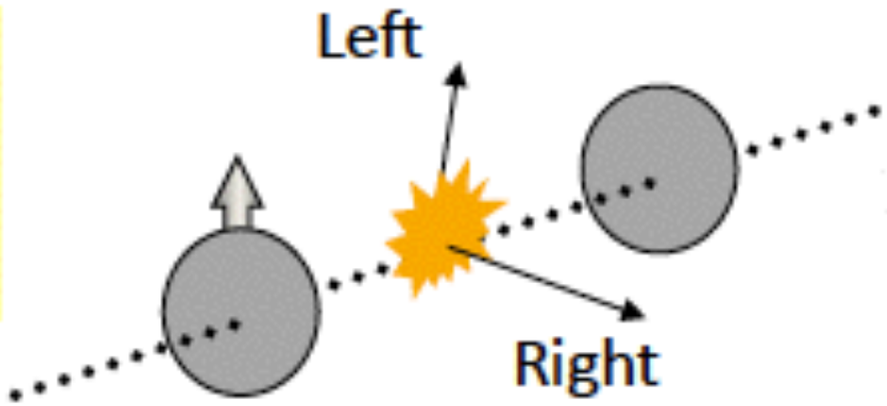


More TSSA Measurements (II)

TSSA: Transversal Single Spin Asymmetry

Transverse Single Spin Asymmetries A_N

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$



Theory Expectation:

Small asymmetries at high energies

(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

A_N ~ O(10^{-4}) theory

Experiments:

ZGS, AGS, FERMILAB to RHIC

$$pp^{\uparrow} \rightarrow \pi + X$$

A_N ~ O(10^{-1}) observed

$$\sqrt{s} = 5 \sim 500 \text{ GeV}$$

large TSSAs up to 40% are observed in light hadron-production over a wide range of beam energies (10-10^4) at forward X_F (>0.5) region, where fractional momentum of transversally polarized nucleon is within 0.1 and 0.5.

More TSSA Measurements (II)

TSSA: Transversal Single Spin Asymmetry

Theoretically,

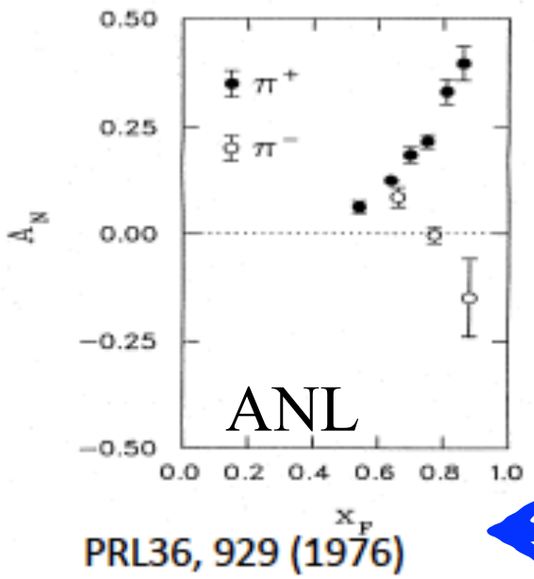
$$A_N \propto \frac{m_q}{\sqrt{s}}$$

Transverse SSA's

from low to high energies

0.29*m_q

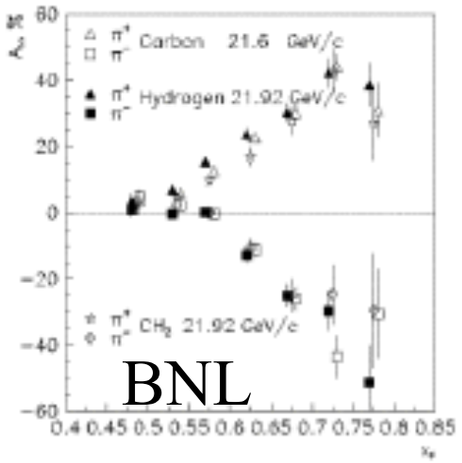
ZGS 12 GeV beam



PRL36, 929 (1976)

0.21*m_q

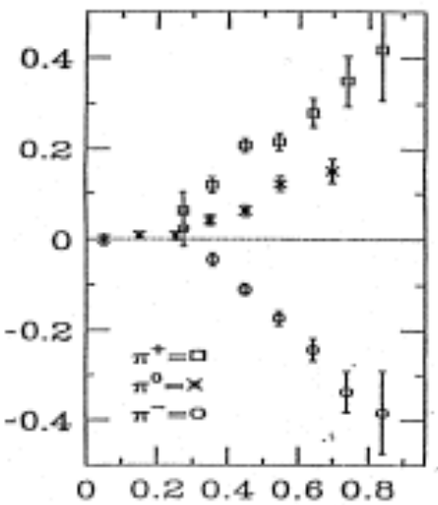
AGS 22 GeV beam



PRD65, 092008 (2002)

0.07*m_q

FNAL 200 GeV beam



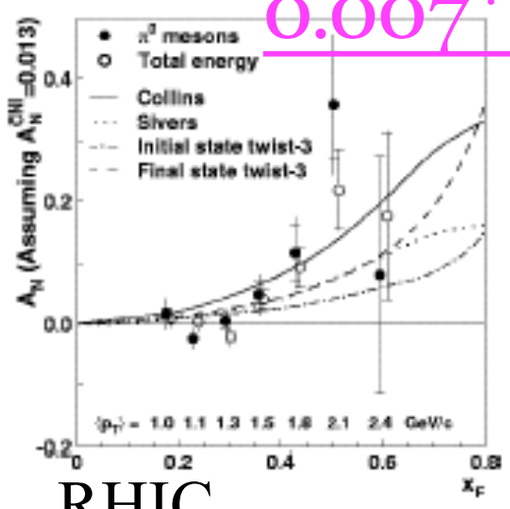
PLB261, 201 (1991)

PLB264, 462 (1991)

fixed target

0.007*m_q

RHIC 20,000 GeV beam



RHIC

PRL (2004)

collider

what does m_q mean here?

Non-Perturbative cross section ——————> Perturbative cross section

asymptotic freedom ——————-> new physics beyond SM

Two Possible TSSA Mechanisms

three transversal quantities are

(1) nucleon's transversal spin (S^n_T);

(2) quark's transversal spin (S^q_T);

(3) quark's transversal momentum (K^q_T)

three PDFs are

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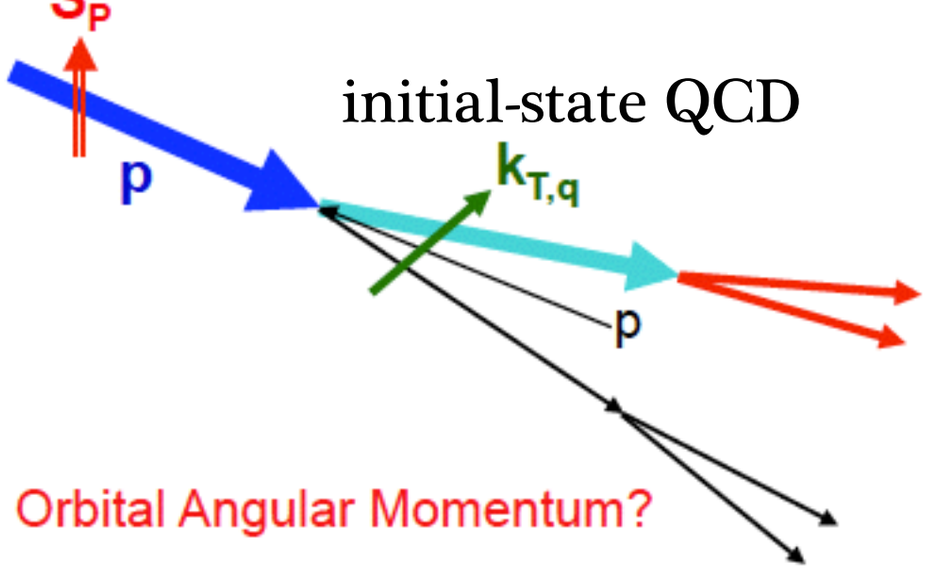
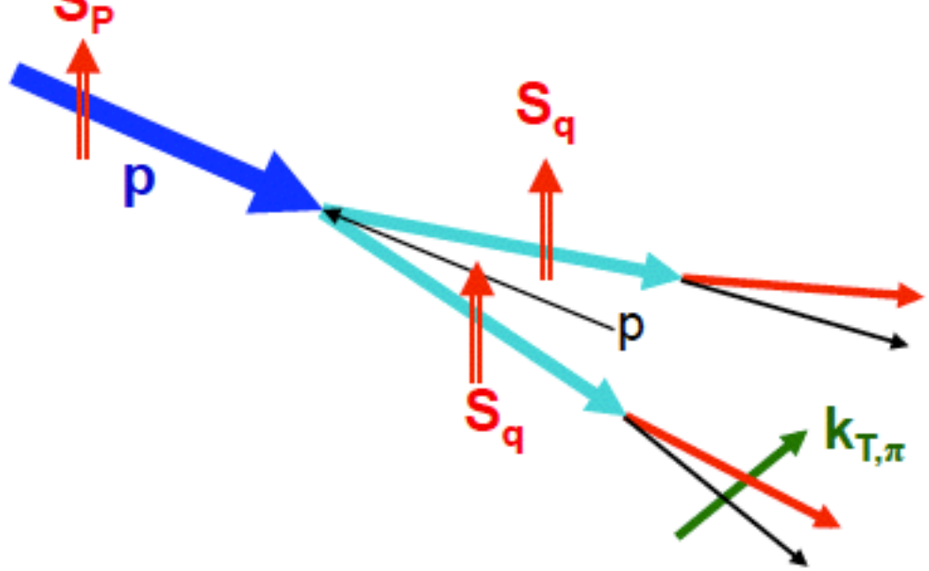




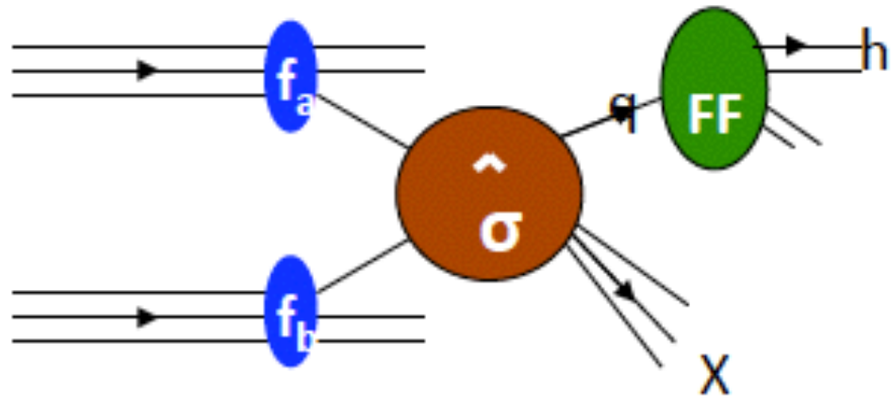
(1) + (3) PRD41 (1990) 83; 43 (1991) 261

(1) + (2) Nucl. Phys. B396 (1993) 161

TSSA measurement in polarized DY

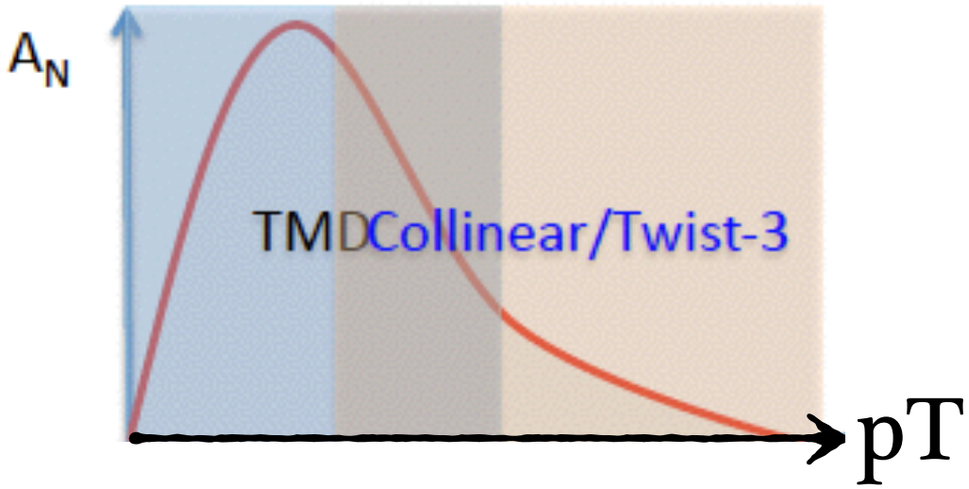
Theory: K_T vs Collinear Factorization

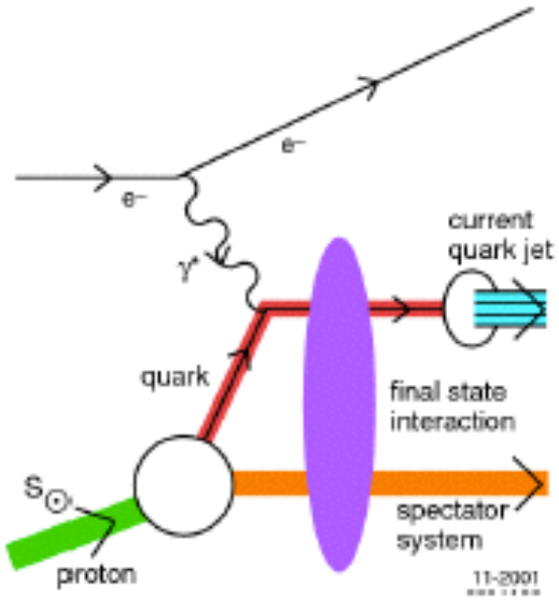
- Tran. Mom. Dep. Funs
  - Sivers Fun
  - Collins Fun

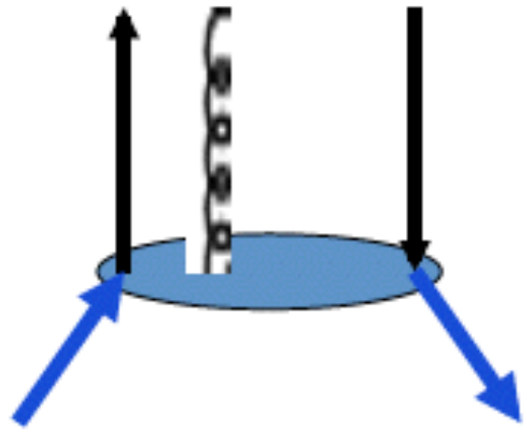


$$\frac{d^3\sigma^{\uparrow}\left(pp^{\uparrow} \to h + X\right)}{dx_1 dx_2 dz} \propto q_i^{\uparrow}(x_1, k_{q,T}) \cdot q_j(x_2) \times \frac{d^3\hat{\sigma}^{\uparrow}(q_i q_j \to q_k q_l)}{dx_1 dx_2} \times FF_{q_{k,l}}(z, p_{h,T})$$

- Twist-3 collinear
  - Quark-gluon correl.
  - Gluon-gluon correl.

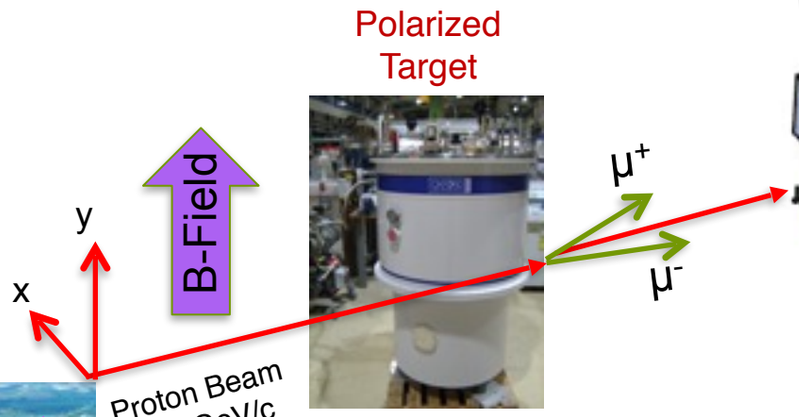




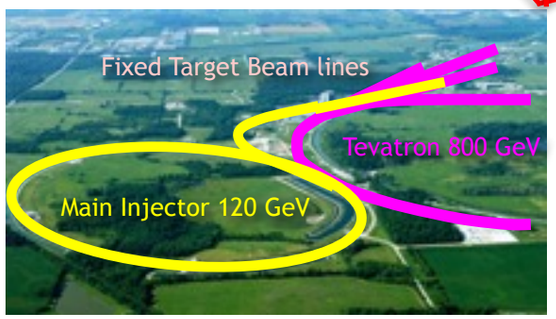


SpinQuest also sheds light on gluon Sivers!

- field: 5T @ 1K
- elliptical: 1.9 cm x 2.1 cm (x,y), l:7.9 cm (z)
- ρ: 0.87 g/cm^3 NH_3 ,
- packing fraction: 0.6
- dilution factor : 0.176
- Polarization <80%>
- lL: 8.6%
- 3 active cells, 1 empty
- Helium consumption 100 l/day



SpinQuest Target

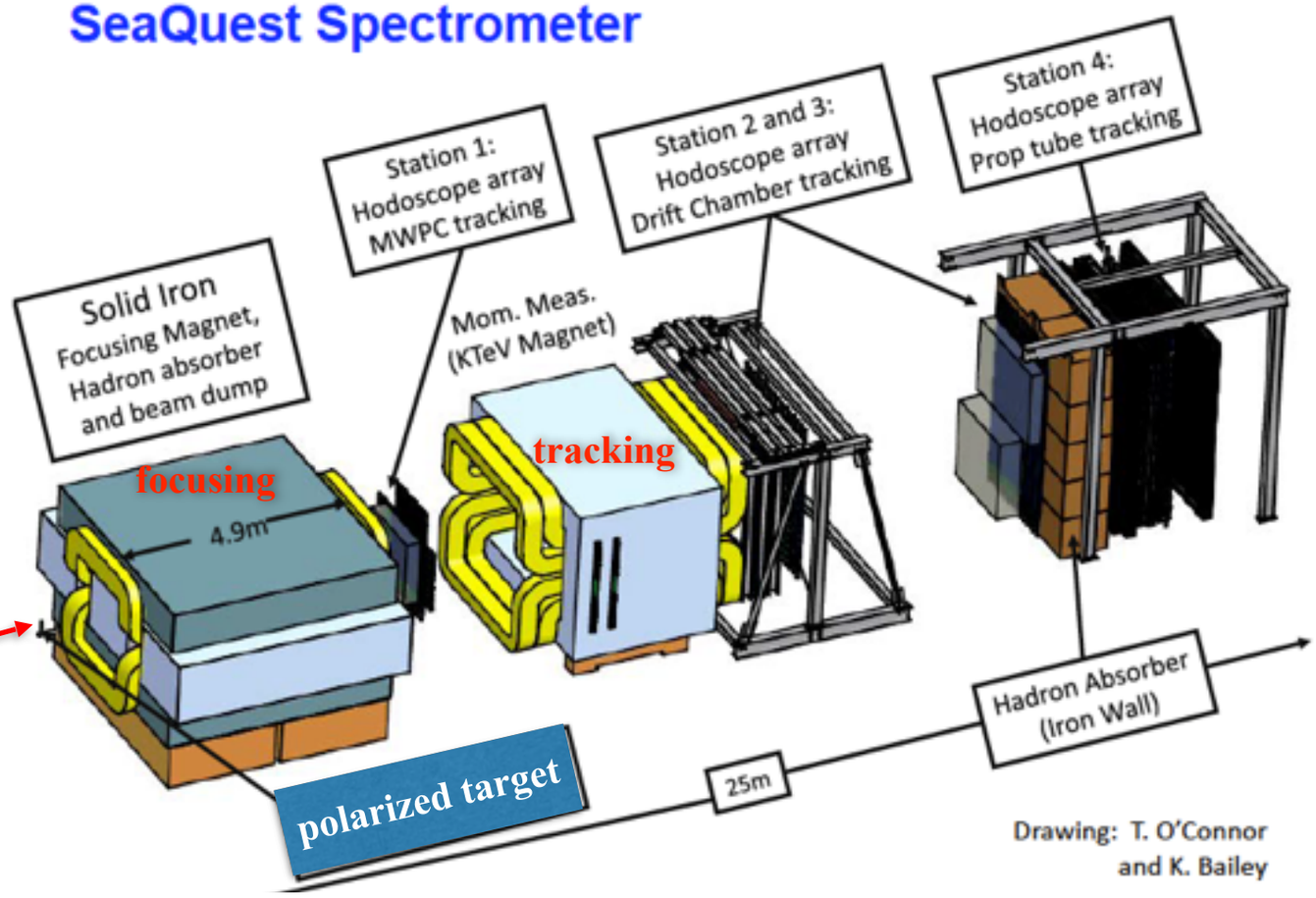


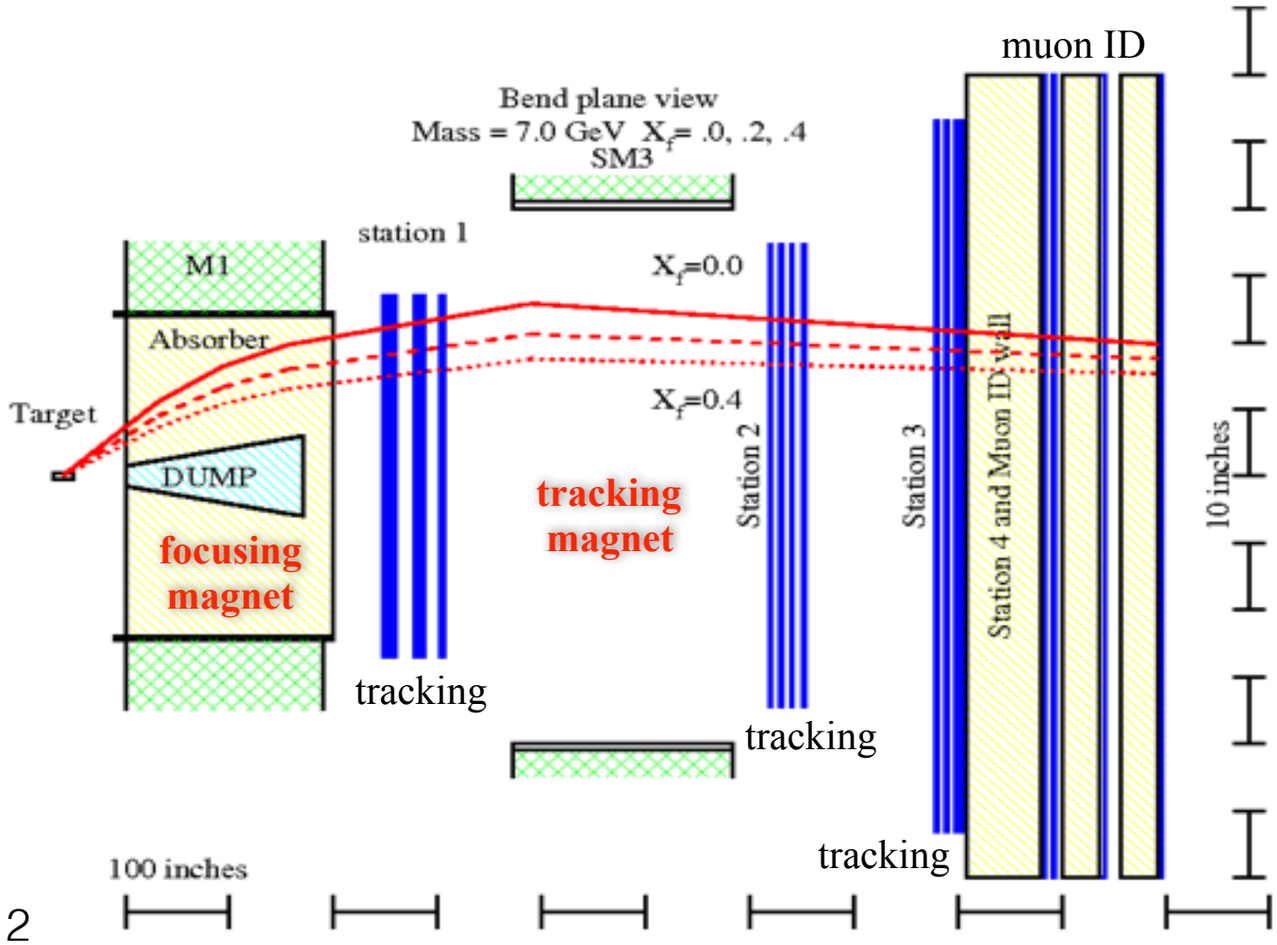
10% of available beam to SeaQuest / 90% to neutrino program

- 2.7·10^{12} p/spill, duty cycle: one 4s spill/minute
- kinematic range 4 < M <9 GeV
- luminosity: 3·10^{35} /cm^2/s (NH_3)
- √s = 15 GeV
- move polarized target ~2m upstream
  → improves target-dump separation
  → moves acceptance to lower x_2

$\mathcal{L}_{int}$ **= 1.82 *10^{42}/cm^2** NH_3 for 2 years

SeaQuest Spectrometer





Ref: Andi Klein (LANL)

2018 fall - 2019 summer

E1039 SpinQuest (No)-beam Commissioning

1. installation is now ongoing;
2. expect initial **BEAM** commissioning in this summer;
3. expect brief commissioning in fall and production data taking by the end of this year;
4. 2 year of data taking (Dec. 2019 - Dec. 2021)